A High-Performance Silicon Tracker for the CBM Experiment at FAIR

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Abstract. The Compressed Baryonic Matter (CBM) experiment at GSI's future international Facility for Antiproton and Ion Research (FAIR) will study strongly interacting matter at high baryon densities. The central component of the fixed-target heavy-ion spectrometer is a high-performance silicon vertex tracker. It applies most advanced pixel and microstrip detectors to track exclusively the charged particles created in the collisions and to reconstruct decay vertices from "open charm". The development of the silicon tracker is challenging and includes R&D on ultra low-mass sensors and support structures, extreme radiation hardness, and fast self-triggered readout.

Keywords: compressed baryonic matter, open charm, silicon vertex tracker, pixel detector, microstrip detector, radiation hardness, low-mass design, data-push readout
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THE CBM EXPERIMENT

The CBM experiment [1] is a fixed-target heavy-ion spectrometer planned at the SIS-300 synchrotron of FAIR [2]. Its research program aims at the study of high-density matter, its structure and the equation-of-state, including the search for deconfinement and chiral phase transitions. The physics program is motivated by results obtained at SPS and at RHIC [3] with collision systems at high temperatures and low baryon-chemical potentials. Future experiments at LHC will probe collisions at even higher temperatures and lower baryon-chemical potentials. The CBM experiment will explore the phase diagram in a complementary region, at high baryon densities, that is largely unexplored. The dense matter will be created in collisions of intense heavy-ion beams extracted from SIS-300 at energies up to 45 GeV/n, with nuclear targets at up to 10^7 interactions/s.

The CBM spectrometer, schematically shown in Fig. 1a, is optimized for the detection of rare and penetrating probes as open charm and di-lepton decays of low-mass vector mesons. Those are important observables for the initial energetic and dense phase of nuclear collisions. The experiment combines a Silicon Tracking System (STS) for exclusive charged-particle tracking and vertexing, installed in a compact magnetic dipole field directly behind the target, with detectors for particle identification (RICH, TRD), time-of-flight (TOF) measurement and electromagnetic calorimetry (ECAL) downstream. A muon identification system and other specific detector configurations are under study.

THE SILICON TRACKING SYSTEM

The Silicon Tracker is CBM's core detector system. The harsh collision environment necessary for the physics studies of CBM requires the adoption of a novel concept for charged-particle tracking and the reconstruction of heavy-flavor decays. It can only be realized with a silicon tracking system of unprecedented performance. The goal is to develop a Silicon Vertex Spectrometer similar to a system recently pioneered by the NA60 experiment [4] at the SPS. A telescope of silicon detectors with high spatial resolution will be arranged in a strong magnetic dipole field just downstream of the target, in front of detectors for particle identification. It will exclusively reconstruct the tracks and momenta of the charged particles created in the collisions and will identify decay vertices of massive short-lived particles containing heavy quarks.

The measurement of "open charm" is one of the prime interests of CBM and at the same time one of the most difficult tasks. The benchmark for the performance of the Silicon Tracking System is the reconstruction of D-mesons through their hadronic decays $D^0 \rightarrow K^-\pi^+$ ($c\tau \approx 124\,\mu$m) and $D^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$ ($c\tau \approx 317\,\mu$m). They have to be identified among the about 1000 charged particles that are produced in a central 25 GeV/n Au+Au collision.

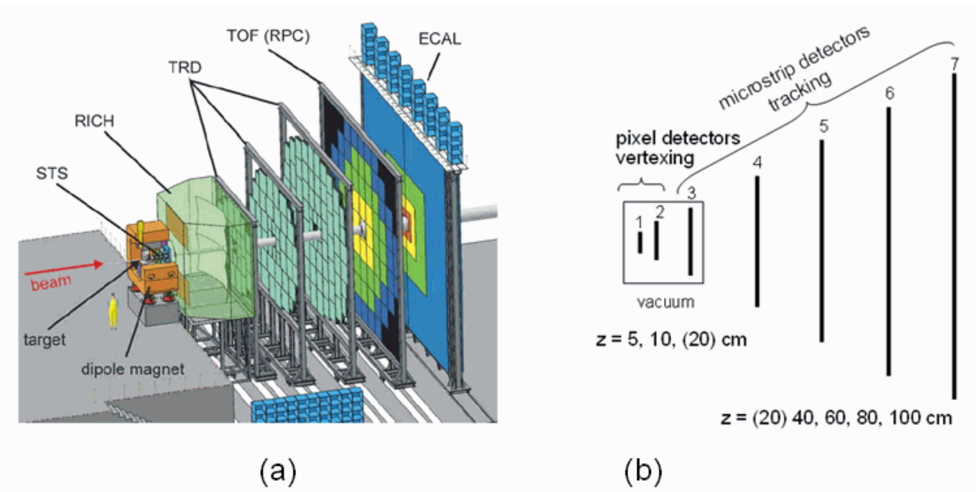

FIGURE 1. (a) Schematical view of the CBM experiment. (b) Concept of the Silicon Tracking System.

Detector Concept

The concept of the Silicon Tracker is shown in Fig. 1b. Seven detector stations with a geometrical acceptance 50–500 mrad are arranged in the 1 m long gap of a superconducting dipole magnet with 1 Tm bending power. This layout achieves a generic momentum resolution better than 1% at 1 GeV/c. Tracking is realized with four thin double-sided microstrip detector planes in the downstream part of the telescope. Three very thin pixel detector planes close to the target provide true space points with very high position resolution for the vertex measurement. They may be installed in vacuum. The first pixel detector station in 5 cm distance to the target has 25 cm^2 active area. The last station at 100 cm extends over 1 m^2. Its size alone already justifies strip technology.

The performance of this detector system was assessed in simulation studies. Minimum bias Au+Au collisions at 25 GeV/nucleon generated with URQMD [5] were reconstructed using a cellular automaton and Kalman filter technique [6]. Double-sided microstrip sensors of 200 μm thickness and 10 μm spatial resolution were assumed in the tracking sector. Despite of combinatorial fake hits, individual tracks are reconstructed with 97% efficiency, high-energy tracks with 99% efficiency. As low as 1% ghost tracks remain when unambiguous track points from one pixel plane are included in the reconstruction. The study indicates that pixel detectors with small sensor cells ($25 \times 25\,\mu\mathrm{m}^2$) in less than 100 μm silicon equivalent and very little event pile-up are the prime requirement to distinguish and resolve the event and D^0 vertices. The D^0 mass peak was then extracted with 10% efficiency. Further studies are being performed to optimize the layout and number of detector stations for several physics measurements.

Detector R&D

Currently available pixel detector technology combines only two out of four performance requirements essential to CBM: Either small pixel size and very low total thickness, or fast readout and radiation tolerance exceeding 10^{13} 1-MeV n_{equiv}. A research project was started aiming at the development of a pixel detector prototype based on monolithic active pixel sensors (MAPS) [7]. The goal is to build on the already excellent position resolution and ultimately small thickness that match the CBM requirements, and to improve their radiation hardness and readout speed. DEPFET [8] sensors are another candidate pixel detector technology with many specifications similar to MAPS. Other activities focus on the development of thin microstrip sensors for the tracking stations, an option of additional hybrid pixel detectors [9] in the central part of the tracker, and on front-end electronics for a self-triggered ("data-pushed") readout.

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